Developing Fuels (DF)

Revision guide

Clarity, confidence, and top grades.

What this storyline covers

- Enthalpy changes and standard definitions
- Bond enthalpies and Hess cycles
- Calorimetry and energy calculations
- Gas volumes and the ideal gas equation
- Alkanes, alkenes and alcohols: naming and shapes
- Structural and E/Z isomerism
- Alkene reactions and electrophilic addition
- Addition polymers
- Catalysis, cracking and fuels
- Atmospheric pollutants and sustainability

Required practicals in this storyline: **PAG1** (reacting masses & gas volumes), **PAG3** (enthalpy by calorimetry), **PAG7** (testing for unsaturation), plus cracking a hydrocarbon.



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How to use this guide

Developing Fuels introduces two large themes — **energetics** and the whole of **introductory organic chemistry**. The enthalpy ideas, the naming and shapes of molecules, and the reaction types you meet here are used again in every later storyline, so time spent here pays off across the course.

How it is assessed

OCR B is context-led, so DF content can appear in **any** of the three written papers, in any context:

- **Paper 1** — Fundamentals of chemistry (110 marks)
- **Paper 2** — Scientific literacy, including the pre-release Advance Notice article (100 marks)
- **Paper 3** — Practical skills in chemistry (60 marks)

How to revise it

- Learn the **definitions in the teal boxes** word-for-word — they are marks you can guarantee.
- Work every **worked example** yourself before reading the solution.
- Practise **drawing mechanisms and structures** by hand — examiners mark the detail.
- Use the **spec checklist** on the last page to confirm you can do every point.

1 Energetics: enthalpy changes

Spec references: DF(d), DF(e), DF(f), DF(g). Practical: PAG3.

Key terms DF(d)

Key definitions

- **Exothermic** — energy is transferred to the surroundings; ΔH is **negative**.
- **Endothermic** — energy is taken in from the surroundings; ΔH is **positive**.
- **Standard conditions** — a pressure of 100 kPa, a stated temperature (usually 298 K), and a concentration of 1 mol dm^{-3} for solutions; the standard state is the physical state under these conditions.
- **Standard enthalpy change of reaction, $\Delta_r H^\ominus$** — the enthalpy change when the amounts shown in the equation react under standard conditions.
- **Standard enthalpy change of combustion, $\Delta_c H^\ominus$** — the enthalpy change when **one mole** of a substance is burned completely in oxygen under standard conditions.
- **Standard enthalpy change of formation, $\Delta_f H^\ominus$** — the enthalpy change when **one mole** of a compound is formed from its elements in their standard states, under standard conditions.
- **Standard enthalpy change of neutralisation, $\Delta_{neut} H^\ominus$** — the enthalpy change when an acid and a base react to form **one mole of water** under standard conditions.

Remember

In an **exothermic** reaction the products are lower in energy than the reactants, so ΔH is **negative**; in an **endothermic** reaction the products are higher, so ΔH is **positive**. Combustion is always exothermic; many — but not all — formation reactions are exothermic.

Measuring enthalpy changes: calorimetry DF(f) — PAG3

$$q = mc\Delta T$$

energy transferred (J) = mass of solution or water (g) × specific heat capacity (4.18 J g^{-1} K^{-1}) × temperature change (K or °C)

- Use the mass of the **water or solution** being heated (1 cm^3 of water ≈ 1 g).
- Find **moles** of the reactant that changes, then divide q by moles to get the enthalpy change **per mole**; add the correct sign (negative if the temperature rises).

Worked example — enthalpy of combustion by calorimetry

Burning 0.46 g of ethanol (M = 46.0) raises the temperature of 100 g of water by 24.0 °C. Find $\Delta_c H$.

$q = mc\Delta T = 100 \times 4.18 \times 24.0 = 10\,032\ J = 10.0\ kJ$

$n(\text{ethanol}) = 0.46 / 46.0 = 0.0100\ mol$

$\Delta_c H = -10.0 / 0.0100 = -1000\ kJ\ mol^{-1}$

Common pitfalls — calorimetry

- Using the mass of the **fuel** instead of the mass of **water** in q = mcΔT.
- Forgetting to convert q from **J to kJ** before dividing by moles.
- Omitting the **negative sign** for an exothermic change.
- The experimental value is **less exothermic** than the data-book value because of **heat loss** to the surroundings and **incomplete combustion**.

Bond enthalpies DF(e)

Key definition

The **average bond enthalpy** is the mean energy needed to break one mole of a particular type of bond in the gaseous state, averaged over a range of molecules.

- **Breaking** bonds is **endothermic** (energy in); **making** bonds is **exothermic** (energy out).
- A **stronger** (and usually **shorter**) bond has a **larger** bond enthalpy.

$$\Delta H = \Sigma(\text{bonds broken}) - \Sigma(\text{bonds made})$$

all bond enthalpies of bonds broken in the reactants, minus all bonds made in the products

Worked example — combustion using bond enthalpies

Estimate ΔH for $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$. Bond enthalpies (kJ mol^{-1}): C–H 413, O=O 498, C=O 805, O–H 464.

broken: 4(C–H) + 2(O=O) = 4(413) + 2(498) = 2648
made: 2(C=O) + 4(O–H) = 2(805) + 4(464) = 3466
ΔH = 2648 – 3466 = –818 kJ mol^{-1}

Exam tip

Bond-enthalpy answers are **estimates**, because the values are averages and apply to **gaseous** species. The values are given in the question — you are marked on the method: count every bond broken and made, and subtract the right way round.

Hess' law and enthalpy cycles DF(g)

- The enthalpy change for a reaction is **independent of the route taken**, so an unknown ΔH can be found from an enthalpy cycle.
- From enthalpy changes of **formation**: $\Delta_r H = \Sigma\Delta_f H(\text{products}) - \Sigma\Delta_f H(\text{reactants})$.
- From enthalpy changes of **combustion**: $\Delta_r H = \Sigma\Delta_c H(\text{reactants}) - \Sigma\Delta_c H(\text{products})$.

Worked example — $\Delta_r H$ from enthalpy changes of formation

$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$. $\Delta_f H$ (kJ mol^{-1}): C_2H_4 +52, H_2O −242, C_2H_5OH −235.

$\Delta_r H = \Sigma\Delta_f H(\text{products}) - \Sigma\Delta_f H(\text{reactants})$
$= (-235) - (52 + (-242)) = -235 - (-190) = -45$ kJ mol^{-1}

Exam tip

A statement of Hess' law is not required, but you must be able to **build and use the cycle**. Draw the arrows, then follow "with the arrow add, against the arrow subtract". For formation cycles the elements sit at the bottom; for combustion cycles the combustion products sit at the bottom.

2 Gases and amount of substance

Spec reference: DF(a). Practical: PAG1.

$$pV = nRT$$

p = pressure (Pa), V = volume (m^3), n = amount (mol), R = 8.314 J mol^{-1} K^{-1}, T = temperature (K)

Units — get these right first

- Pressure in **Pa** (1 kPa = 1000 Pa).
- Volume in **m^3**: 1 dm^3 = 1 × 10^{-3} m^3; 1 cm^3 = 1 × 10^{-6} m^3.
- Temperature in **K**: K = °C + 273.

- At **room temperature and pressure (RTP)** the molar gas volume is **24.0 dm^3 mol^{-1}**, so n = V (in dm^3) ÷ 24.0. Both 24.0 dm^3 mol^{-1}

and R are given on the Data Sheet.

Worked example — the ideal gas equation

Find the volume of 0.50 mol of gas at 100 kPa and 298 K.

$V = nRT / p = (0.50 \times 8.314 \times 298) / 100\,000 = 0.0124\ m^3 = 12.4\ dm^3$

Check: at RTP, $0.50 \times 24.0 = 12\ dm^3$ — consistent.

Common pitfall

Almost all lost marks here are **unit errors**: pressure left in kPa, volume left in cm^3 or dm^3, or temperature left in °C. Convert **before** substituting.

Measuring gas volumes PAG1

Collect the gas in a **gas syringe** (or over water) and read the volume at the plunger; combine this with reacting-mass and mole calculations to find a formula or check an equation.

3 Bonding and shapes in organic molecules

Spec references: DF(b), DF(c).

σ- and π-bonds DF(b)

Key definitions

- A **σ-bond** forms by **end-on** overlap of orbitals directly between the two nuclei; it allows free rotation. Every single bond is a σ-bond.
- A **π-bond** forms by **sideways** overlap of p-orbitals above and below the bond axis; it restricts rotation. A C=C double bond is one σ-bond plus one π-bond.

Shapes and 3-D representation DF(c)

- Around a saturated (single-bonded) carbon the shape is **tetrahedral**, bond angle **109.5°**.
- Around each carbon of a C=C the shape is **trigonal planar**, bond angle **120°**.
- Show 3-D shape with **wedges**: a **solid wedge** comes towards you, a **dashed wedge** goes away from you, and ordinary lines lie in the plane of the paper.

4 Organic families and naming

Spec references: DF(l), DF(m), DF(r).

Key terms DF(l)

Key definitions

- **Homologous series** — a family of compounds with the same functional group and general formula, each member differing by CH_2, showing a gradual change in physical properties and similar chemical reactions.
- **Functional group** — the atom or group of atoms responsible for the characteristic reactions of a compound.
- **Saturated** — containing only single C–C bonds; **unsaturated** — containing a C=C or C≡C bond.
- **Aliphatic** — carbon atoms joined in straight or branched chains (or non-aromatic rings); **aromatic / arene** — containing a benzene ring.

The main homologous series DF(m)

Series	General formula	Functional group	Example
Alkanes	C_nH_{2n+2}	none (saturated)	propane, C_3H_8
Cycloalkanes	C_nH_{2n}	saturated ring	cyclohexane, C_6H_{12}
Alkenes	C_nH_{2n}	C=C	propene, C_3H_6
Alcohols	$C_nH_{2n+1}OH$	–OH	propan-1-ol, C_3H_7OH

Naming rules

- **Stem** = the longest carbon chain containing the functional group: meth (1), eth (2), prop (3), but (4), pent (5), hex (6), hept (7), oct (8), non (9), dec (10).

- **Suffix** shows the group: -ane, -ene, -ol. Add a **locant** (lowest possible number) for its position, e.g. but-2-ene, propan-2-ol.
- **Prefixes** for branches (methyl, ethyl) and substituents (chloro, bromo) are listed **alphabetically**, using di-, tri- for repeats and locants for position.

Structural formulae DF(r)

- **Full (displayed)** — every atom and every bond drawn out.
- **Shortened (condensed)** — e.g. $CH_3CH_2CH_2OH$.
- **Skeletal** — the carbon chain as a zig-zag of lines; carbons and their hydrogens are implied, and functional groups are shown.

5 Isomerism

Spec references: DF(s), DF(t).

Structural isomerism DF(s)

> **Key definition**
> **Structural isomers** have the same molecular formula but a different structural formula.

- **Chain** isomers — a different arrangement of the carbon skeleton (e.g. butane and methylpropane).
- **Position** isomers — the functional group sits on a different carbon (e.g. butan-1-ol and butan-2-ol).
- **Functional-group** isomers — the same atoms form a different functional group (e.g. an alcohol and an ether).

Stereoisomerism: E/Z and cis–trans DF(t)

> **Key definition**
> **E/Z stereoisomers** have the same structural formula but a different arrangement of groups in space, caused by **restricted rotation** about a C=C double bond when the two groups on each carbon differ.

- The π-bond prevents rotation about C=C, so the groups are locked in position.
- **E/Z** is used when each carbon of the C=C carries an H: **Z** = the two like groups on the **same** side (from *zusammen*), **E** = on **opposite** sides (from *entgegen*).
- **cis/trans** is used when one of the groups on each carbon is the same: **cis** = same side, **trans** = opposite sides. Example: cis- and trans-but-2-ene.

> **Common pitfall**
> A molecule shows E/Z (or cis–trans) isomerism only if **each** carbon of the C=C carries **two different** groups. Knowledge of the full Cahn–Ingold–Prelog priority rules is not required at this level.

6 Reactions of alkanes and alkenes

Spec references: DF(n), DF(o), DF(q). Practical: PAG7.

Combustion DF(n)

- **Complete combustion** (plenty of oxygen) gives **CO_2 and H_2O**; it is strongly exothermic, which is why hydrocarbons are used as fuels.
- **Incomplete combustion** (limited oxygen) gives **carbon monoxide (CO)** and/or **carbon (soot)** as well as water.
- Example: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ (complete); $2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O$ (incomplete).
- Alcohols and alkenes burn in the same way: balance C, then H, then O.

Addition reactions of alkenes DF(o) — PAG7

The C=C double bond is an area of **high electron density**, so it is far more reactive than a C–C single bond and undergoes **addition** reactions.

Reagent	Conditions	Product
Bromine, Br_2	room temperature	a dibromoalkane (1,2-dibromo compound)
Hydrogen bromide, HBr	room temperature	a bromoalkane
Hydrogen, H_2	Ni catalyst, heat and pressure (or Pt at RTP)	an alkane
Steam, H_2O	H_3PO_4 catalyst, heat and pressure (or conc. H_2SO_4, then water)	an alcohol

Exam tip — test for unsaturation (PAG7)

Shake the compound with **bromine water**. An **alkene decolourises it** (orange → colourless) as the C=C adds across the bromine; an **alkane leaves it orange**. This is the standard test for a C=C double bond.

Electrophilic addition mechanism DF(q)

Key definitions

- **Addition** — two molecules join to form one; the C=C becomes a C–C.
- **Electrophile** — an electron-pair acceptor (attracted to areas of high electron density).
- **Carbocation** — an organic ion with a positively charged carbon atom.

- **Step 1:** the electron-rich C=C attracts the electrophile. A **curly arrow** from the C=C to the H of H–Br (or to a Br of Br–Br) forms a new bond, while a second curly arrow shows the bonding pair moving onto the leaving atom, which becomes Br^-.
- **Intermediate:** a positively charged **carbocation** forms (for bromine, a bromonium ion may be shown instead).
- **Step 2:** a curly arrow from a lone pair on Br^- forms a bond to the carbocation, giving the addition product.
- **Supporting evidence:** if another anion (e.g. Cl^- from added NaCl) is present during bromination, a mixed product containing chlorine is also formed — this confirms a positively charged intermediate that reacts with whichever anion is nearby.

7 Addition polymers

Spec reference: DF(p).

Key definition

In **addition polymerisation**, many small unsaturated molecules (**monomers**, each with a C=C) join together to form one long-chain molecule (the **polymer**), with **no other product**.

- To draw the **repeat unit**: open the C=C double bond, draw the two carbons singly bonded with their side groups kept, add a bond through each end, and write a subscript **n** outside square brackets.
- Examples: ethene → poly(ethene); propene → poly(propene); chloroethene → poly(chloroethene), i.e. PVC.
- To work **backwards**: take one repeat unit and put the double bond back between the two carbons to find the monomer.

8 Catalysis and cracking

Spec references: DF(h), DF(i), DF(j).

Catalysts DF(h), DF(i)

Key definitions

- **Catalyst** — a substance that speeds up a reaction by providing an alternative route of **lower activation energy**, and is not used up overall.
- **Catalysis** — the action of a catalyst.
- **Heterogeneous catalyst** — one in a **different physical state** from the reactants (typically a solid catalyst with gaseous or liquid reactants).
- **Catalyst poison** — a substance that binds to the catalyst surface and stops it working.

Simple model of a heterogeneous catalyst: reactant molecules are **adsorbed** onto **active sites** on the surface; this weakens their bonds and holds them close together in the right orientation, so they react; the products then **desorb**, freeing the site for more reactant.

Cracking DF(j)

- **Cracking** breaks long-chain alkanes into shorter, more useful **alkanes and alkenes**.
- **Catalytic cracking** passes the hydrocarbon vapour over a **heated catalyst**; it yields branched and cyclic molecules for petrol and alkenes for making polymers (specific catalysts are not required).

Exam tip — cracking practical

Heat the catalyst strongly and pass the **hydrocarbon vapour** over it; collect the gaseous product over water and test it with **bromine water** — decolourising shows an **alkene** has formed. Remove the delivery tube from the water **before** you stop heating, to avoid suck-back.

9 Fuels, pollutants and sustainability

Spec references: DF(k), DF(u).

Atmospheric pollutants DF(k)

Pollutant	Main source	Problem	How it is reduced
Particulates (soot, C)	incomplete combustion of fuels	respiratory problems; smog	more complete combustion; filters
Unburnt hydrocarbons	incomplete combustion	photochemical smog	catalytic converters
Carbon monoxide, CO	incomplete combustion	toxic; reduces oxygen transport in the blood	catalytic converters; ensure complete combustion
Carbon dioxide, CO_2	complete combustion	greenhouse gas; contributes to climate change	burn less fuel; carbon capture and storage
Oxides of nitrogen, NO_x	N_2 and O_2 reacting at the high temperature in an engine	acid rain; photochemical smog	catalytic converters
Oxides of sulfur, SO_x	sulfur impurities in the fuel	acid rain	remove sulfur from fuels; flue-gas desulfurisation

A **catalytic converter** can remove several pollutants at once, e.g. $2CO + 2NO \rightarrow 2CO_2 + N_2$.

Choosing sustainable fuels DF(u)

- **Fossil fuels** — energy-dense, readily available, with established infrastructure, but **finite** and a major source of CO_2 and pollutants.
- **Biofuels** (e.g. bioethanol, biodiesel) — **renewable** and close to carbon-neutral in use, but compete with food crops for land and water.
- **Hydrogen** — burns to give **only water**, but is hard to store and transport, and its production needs energy that should come from a clean source to be worthwhile.
- Choosing a fuel means weighing energy supply against cost, availability, and environmental impact; relevant data will be given in the exam.

P Required practicals in this storyline

These PAG activities are most likely to be examined in Paper 3, but the techniques can appear in any paper.

PAG	Activity	What to be able to do
PAG1	Reacting masses, moles & gas volumes	measure a gas volume with a gas syringe; use pV = nRT or the molar gas volume (24.0 $dm^3\ mol^{-1}$) in calculations
PAG3	Enthalpy by calorimetry	measure the temperature change when reactions occur in solution or a flammable liquid burns; use q = mcΔT and calculate ΔH per mole; explain heat-loss errors
PAG7	Testing for unsaturation	add bromine water; an alkene (C=C) decolourises it, an alkane does not
—	Cracking a hydrocarbon	pass a hydrocarbon vapour over a heated catalyst, collect the product and test it with bromine water for unsaturation; avoid suck-back

Exam tip — practical accuracy language

Practical marks come from precise technique and error analysis: reading a gas syringe correctly, using a **lid and insulation** to cut heat loss in calorimetry, recording an accurate **temperature change**, and identifying the apparatus with the largest **percentage uncertainty**.

Spec coverage checklist — can you do every point?

Every assessable learning outcome for Developing Fuels, with where it is covered in this guide. Tick each one once you can do it confidently.

DF(a)	Mole calculations involving gas volumes (including pV = nRT), equations and enthalpy changes; measure volumes of gases — §2
DF(b)	Bonding in organic compounds as σ- and π-bonds — §3
DF(c)	Relate molecular shape to structural formula; use solid and dashed wedges — §3
DF(d)	Enthalpy terms: exothermic, endothermic, standard conditions, Δ_rH, Δ_cH, Δ_fH, $\Delta_{neut}H$ — §1
DF(e)	Average bond enthalpy; bond breaking and making; relation to the overall enthalpy change — §1
DF(f)	Measure energy transferred and calculate enthalpy changes ($q = mc\Delta T$) — §1
DF(g)	Enthalpy changes from enthalpy cycles and level diagrams (Hess' law) — §1
DF(h)	Terms: catalyst, catalysis, catalyst poison, heterogeneous — §8
DF(i)	A simple model for the function of a heterogeneous catalyst — §8
DF(j)	Cracking and the use of catalysts in cracking; crack a hydrocarbon vapour — §8
DF(k)	Origin, effects and reduction of atmospheric pollutants (particulates, unburnt hydrocarbons, CO, CO_2, NO_x, SO_x) — §9
DF(l)	Terms: aliphatic, aromatic, arene, saturated, unsaturated, functional group, homologous series — §4
DF(m)	Naming, general and structural formulae of alkanes, cycloalkanes, alkenes and alcohols — §4
DF(n)	Balanced equations for complete and incomplete combustion — §6
DF(o)	Addition reactions of alkenes (Br_2, HBr, H_2/catalyst, steam/catalyst); test for unsaturation — §6
DF(p)	Addition polymerisation; relate polymer to monomer and vice versa — §7
DF(q)	Terms addition, electrophile, carbocation; electrophilic addition mechanism with curly arrows; supporting evidence — §6
DF(r)	Structural formulae: full, shortened and skeletal — §4
DF(s)	Structural isomerism and structural isomers — §5
DF(t)	Stereoisomerism about C=C: E/Z and cis–trans — §5
DF(u)	Benefits and risks of fossil fuels and alternative fuels (biofuels, hydrogen); sustainable choices — §9